The Motional Stark Effect (MSE) Diagnostic on the National Spherical Torus Experiment (NSTX)

F. M. LEVINTON

NOVA PHOTONICS, INC.

Presented at the 45th Annual Meeting of the

American Physical Society – Division of Plasma Physics

October 27-31, 2003

Albuquerque, New Mexico

ABSTRACT

Nova Photonics, Inc.

The adoption of the motional Stark effect (MSE) polarimetry diagnostic is due to its very good temporal and spatial resolution of the q-profile, combined with its exceedingly good accuracy. This has resulted in many important scientific contributions towards our understanding of stability and transport. Despite the success of MSE on mid to large size devices, with magnetic fields above 1 Tesla, it has not been implemented on low field or small experiments. This is due to the large expense of a neutral beam and/or the inability of the technique to work at magnetic fields below 0.75 Tesla. Two approaches are being developed to remedy this; (1)MSE-LIF using laser-induced fluorescence (LIF), with a small diagnostic neutral beam, and (2)MSE-CIF using collsion-

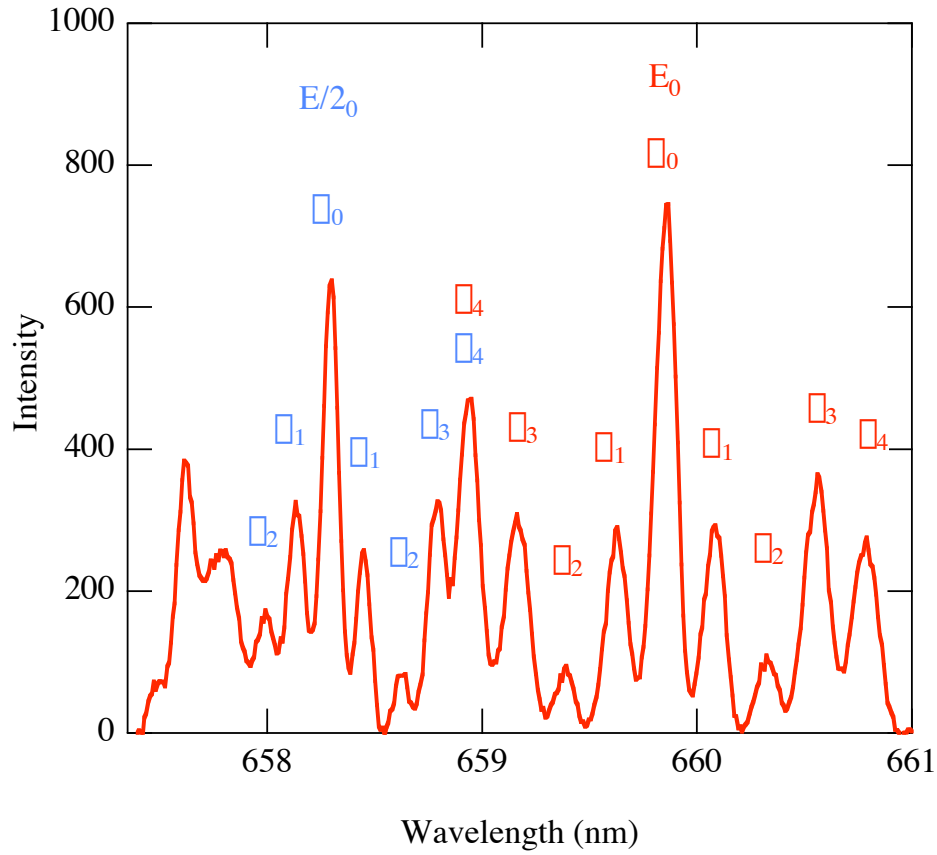
ally induced fluorescence (CIF) to allow the MSE technique to function at significantly lower magnetic fields than previously demonstrated. This work describes the implementation of the MSE-CIF diagnostic on NSTX which views the heating beam with 8 inch collection optics, imaged onto a fiber array. The optical system is configured to maximize the polarization fraction by reducing the Doppler broadening from the heating beam. In addition, a spectral filter with high throughput and high resolution is required to achieve the necessary signal-to-noise. This can be achieved with a wide field Lyot filter. This will permit MSE data to be obtained at magnetic fields >0.3 Tesla. A wide field tunable birefringent filter has been developed that has the required throughput with a bandwidth of $\sim$ 0.06 nm.

Principle of the Motional Stark Effect

- Based on $\vec{\mathrm{E}} = \vec{\mathrm{v}} \times \vec{\mathrm{B}}$ electric field induced by propagation of a neutral beam across a magnetic field.
- Electric field causes spectral splitting and linear polarization of the emitted radiation known as the Stark effect.
- Background plasma causes excitation of neutral beam atoms and Doppler shifted emission (H_α).
- Good beam penetration.
- Good spatial resolution-intersection of sight-line with neutral beam.

Stark Spectra from TFTR

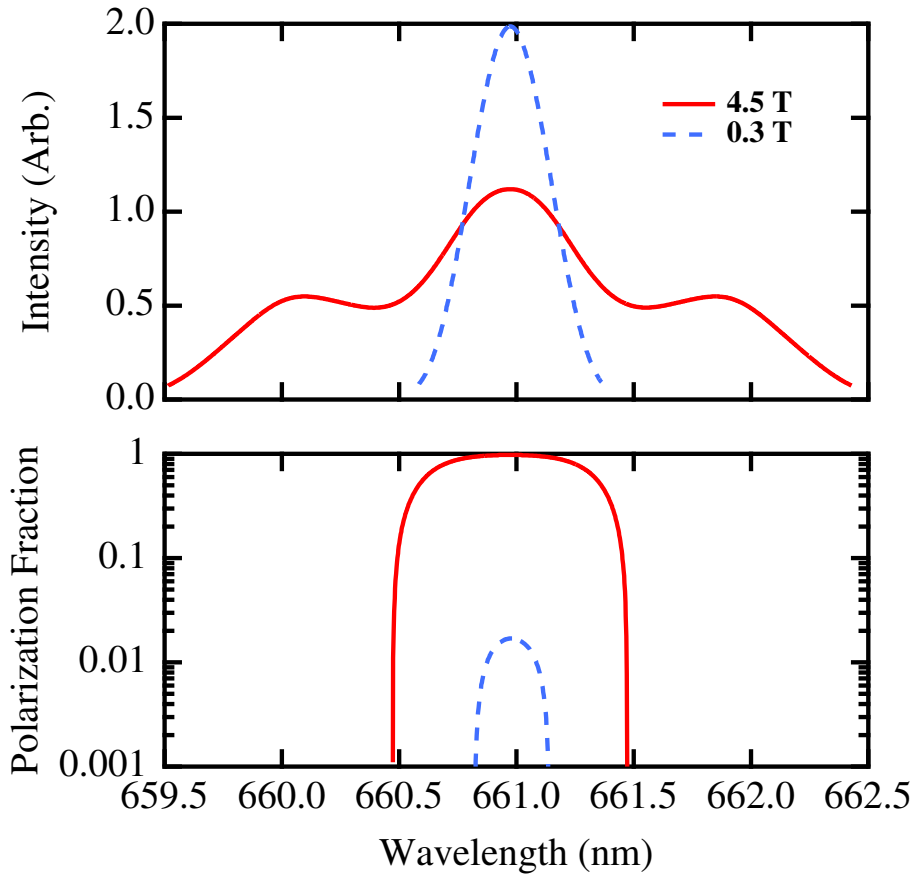
Nova Photonics, Inc.



- $\vec{E} = \vec{v} \times \vec{B}$ electric field is $\sim$ 200 kV/cm at 4.5 T, resulting in a spectral splitting.
- $\Delta m = 0(\pm 1)$, $\pi(\sigma)$ component, are polarized parallel (perpendicular) to the electric field.
- Spectral linewidth is determined by geometric broadening and beam temperature.
- Spectral overlap between π and σ lines reduces polarization fraction and signal-to-noise.

Low Polarization Fraction at Low Field

Nova Photonics, Inc.



$$P_f = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}}$$

$$S/N \propto P_f \sqrt{N}$$

- Numerical convolution of the MSE spectra including filter, beam, and optics broadening.
- At 4.5 T there is a good separation of the π and σ components. At 3 kG overlap of spectral lines leads to a low polarization fraction.

MSE at Low Magnetic Field

Nova Photonics, Inc.

Two different approaches to extend MSE to low magnetic fields.

1. **Optimize optics to reduce geometric spectral broadening.**
   - **Spectral broadening is from the finite optics and image size. Optimization of the optics can reduce the spectral width.**
   - **Development of high resolution, high throughput filter to extend measurements to ~ 0.3 T.**
2. **Laser induced fluorescence (LIF).**
   - **Optically pump $n = 2 \longrightarrow n = 3$ and observe fluorescence with separate optical system.**
   - **This is estimated to work at fields as low as ~ 0.1 T.**

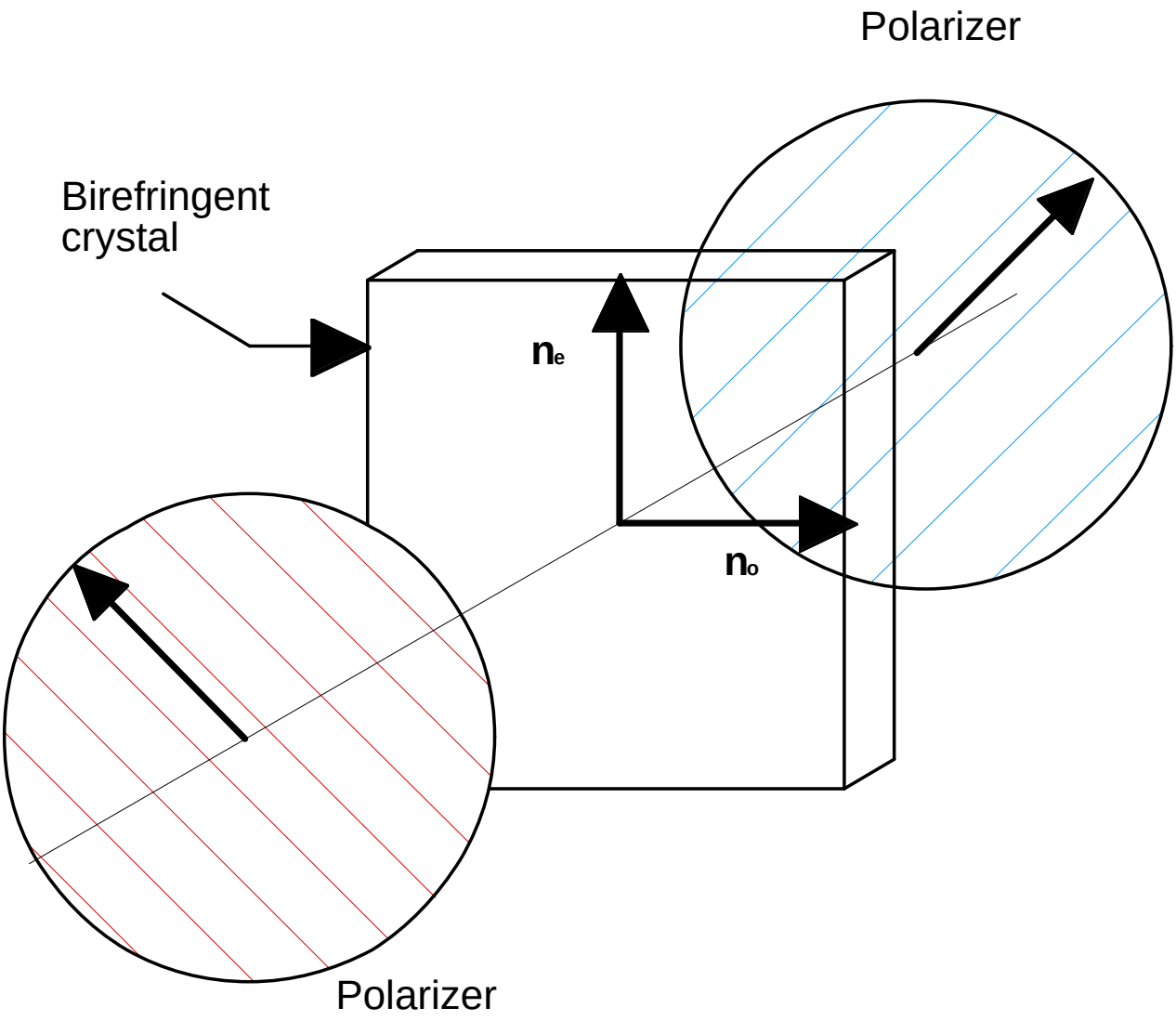
High Resolution Lyot Spectral Filter

Nova Photonics, Inc.

- To obtain a good signal-to-noise ratio a spectral filter with both high throughput and high resolution is required.
- This can be obtained using a wide angle Lyot filter.
- This uses a birefringent crystal with its optic axis oriented at 45° with respect to a pair of polarizers.
- The phase retardation is; $\Gamma = (2\pi/\lambda)\Delta nd$.
- The transmitted intensity; $T = cos^2\Gamma/2$.
- A tunable multiple stage filter has been developed for MSE-CIF.

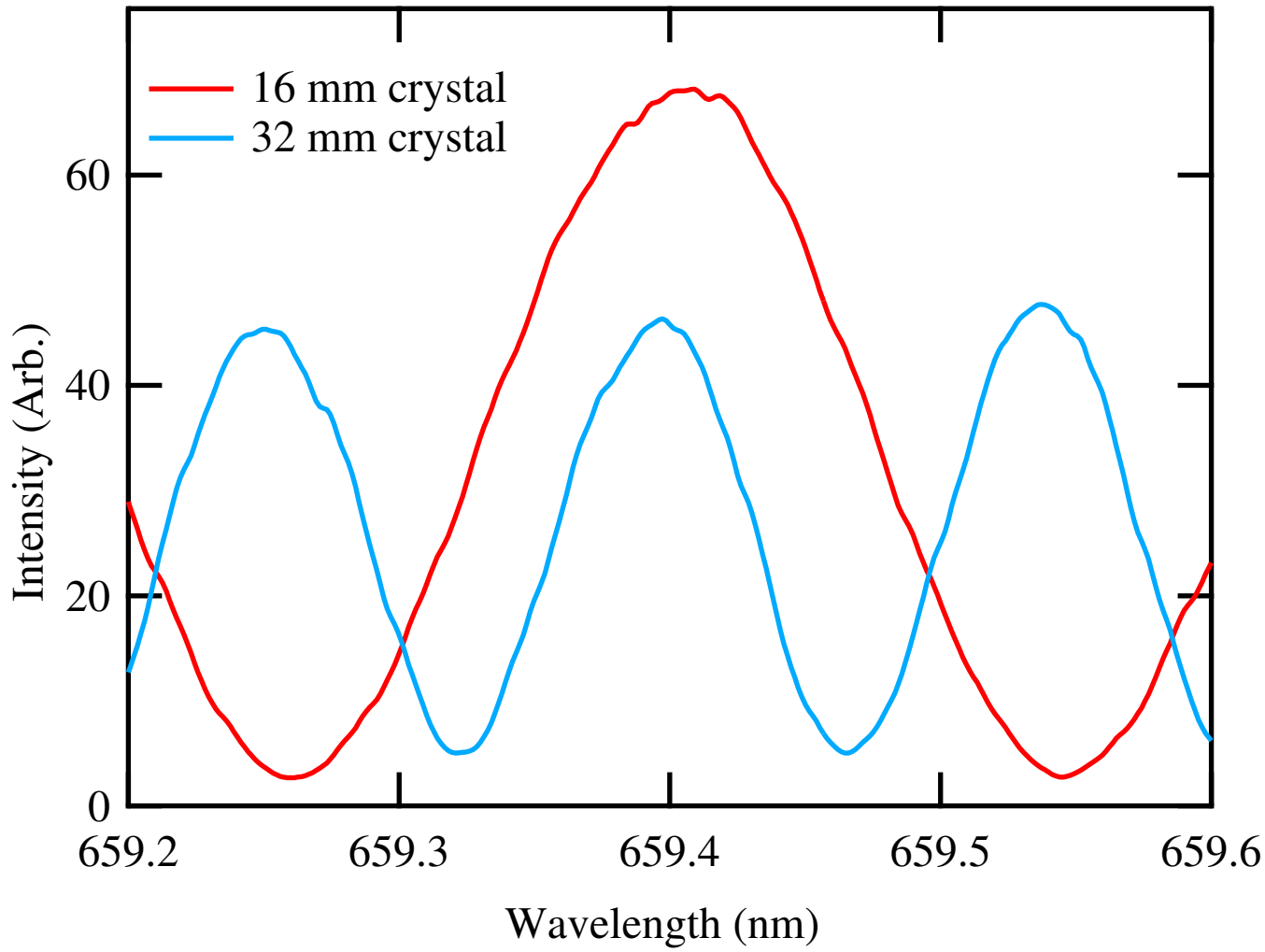
Lyot Filter

Nova Photonics, Inc.



Development of a High Resolution Spectral Filter for MSE-CIF

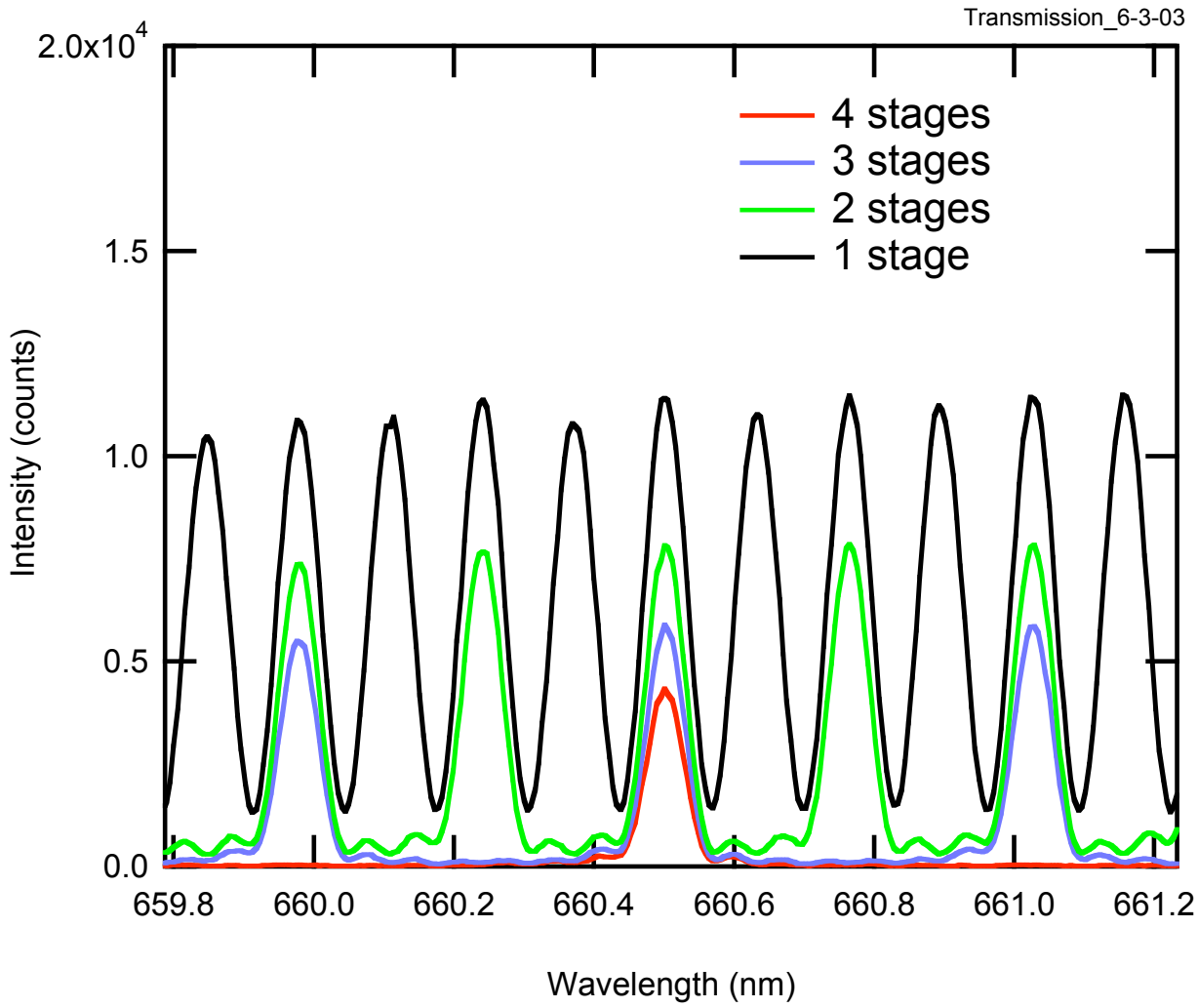
Nova Photonics, Inc.



- **Lithium Niobate crystals used for filter.**
  - **Birefringence homogeneity meets requirements.**
  - **Temperature controlled to $\pm.01°$ C.**
  - **Wavelength tuned electro-optically.**

Four Stage Filter for MSE-CIF

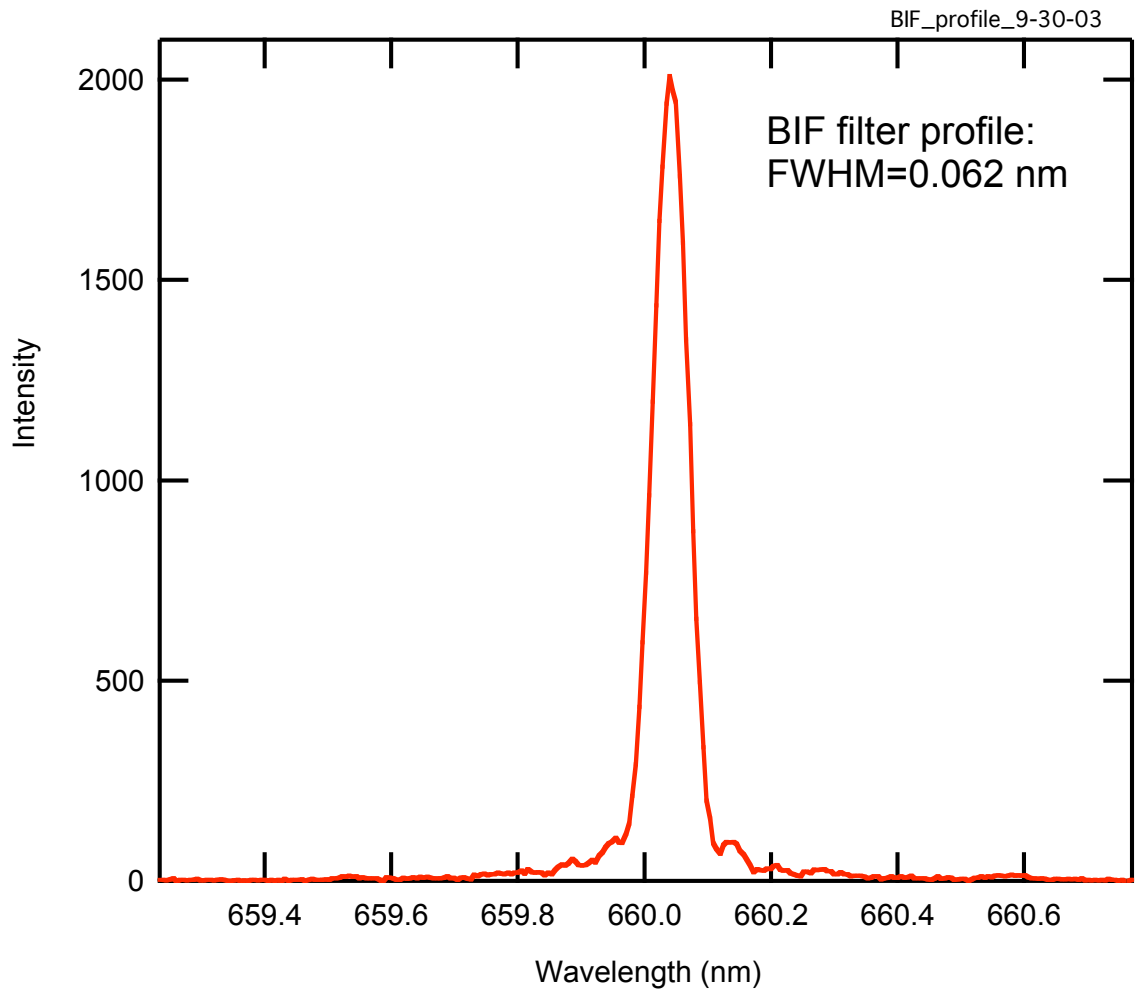
Nova Photonics, Inc.



- **Four stage filter development completed.**
- **Wavelength tuned electro-optically.**

Four Stage Filter for MSE-CIF

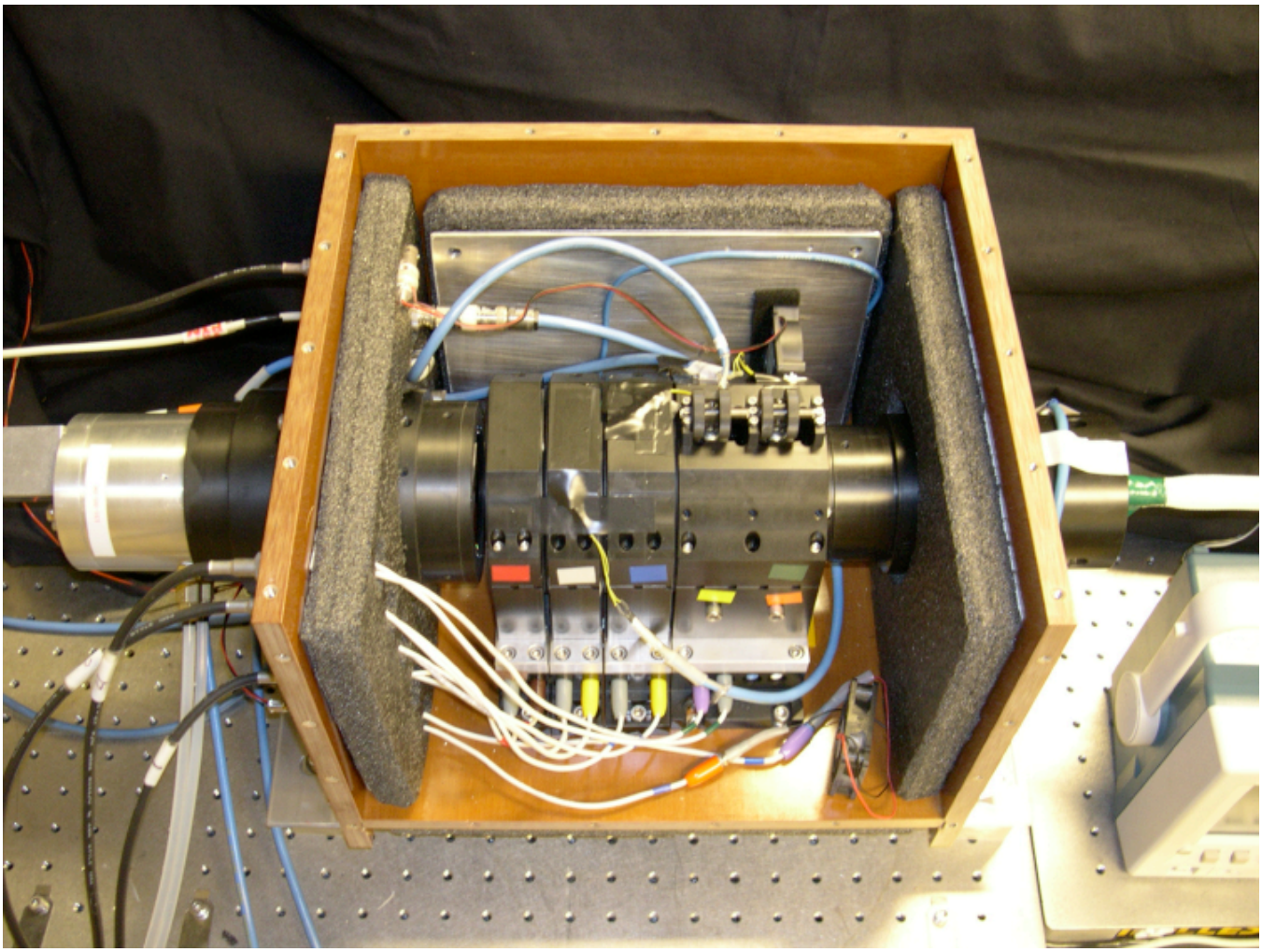
Nova Photonics, Inc.



- **Four stage filter development completed.**
- **Wavelength tuned electro-optically.**

Filter and Optics Enclosure

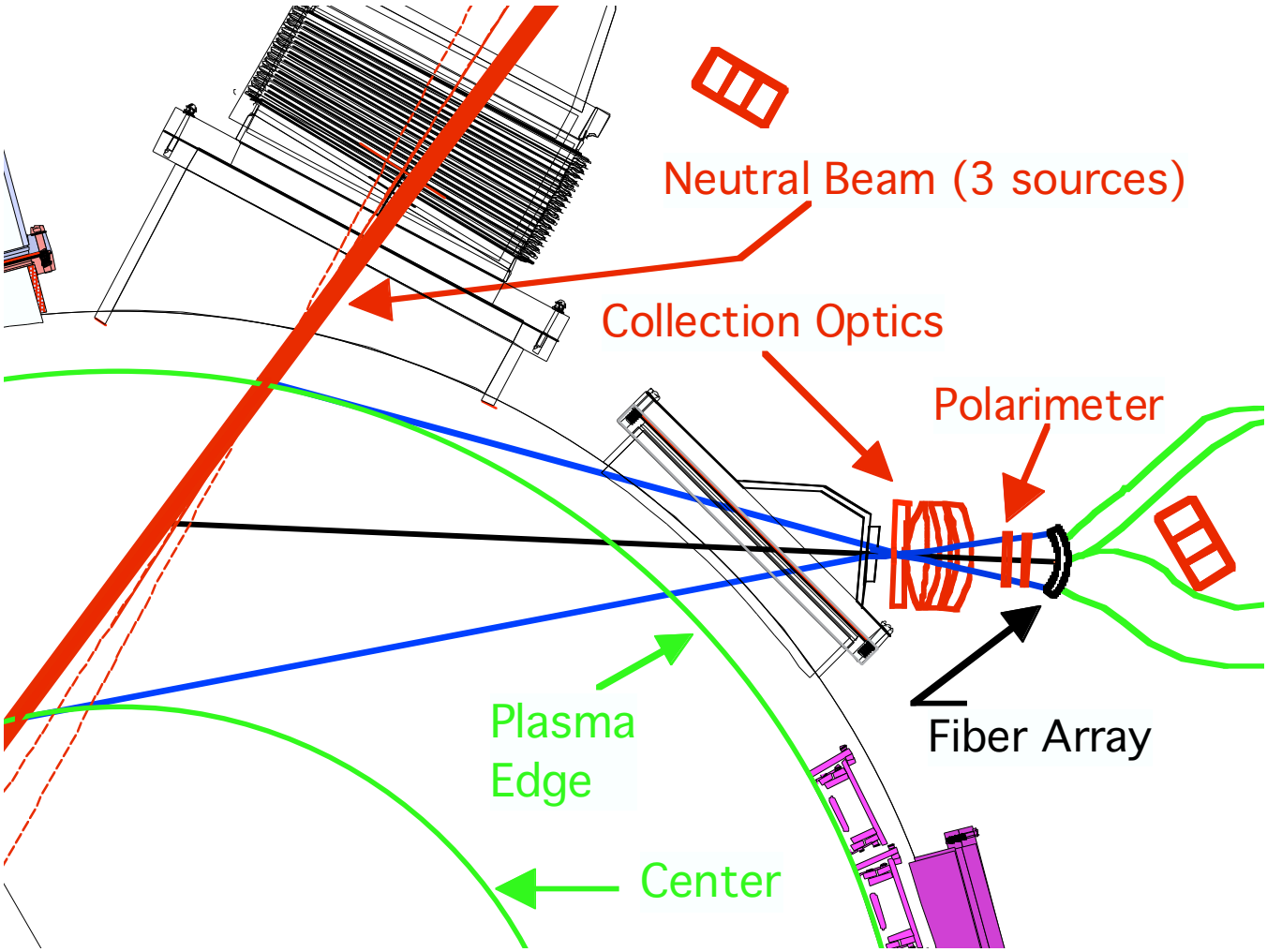
Nova Photonics, Inc.



- **Enclosure contains collimating and focusing optics, APD detector, and temperature control.**
- **Tuning is done electro-optically.**

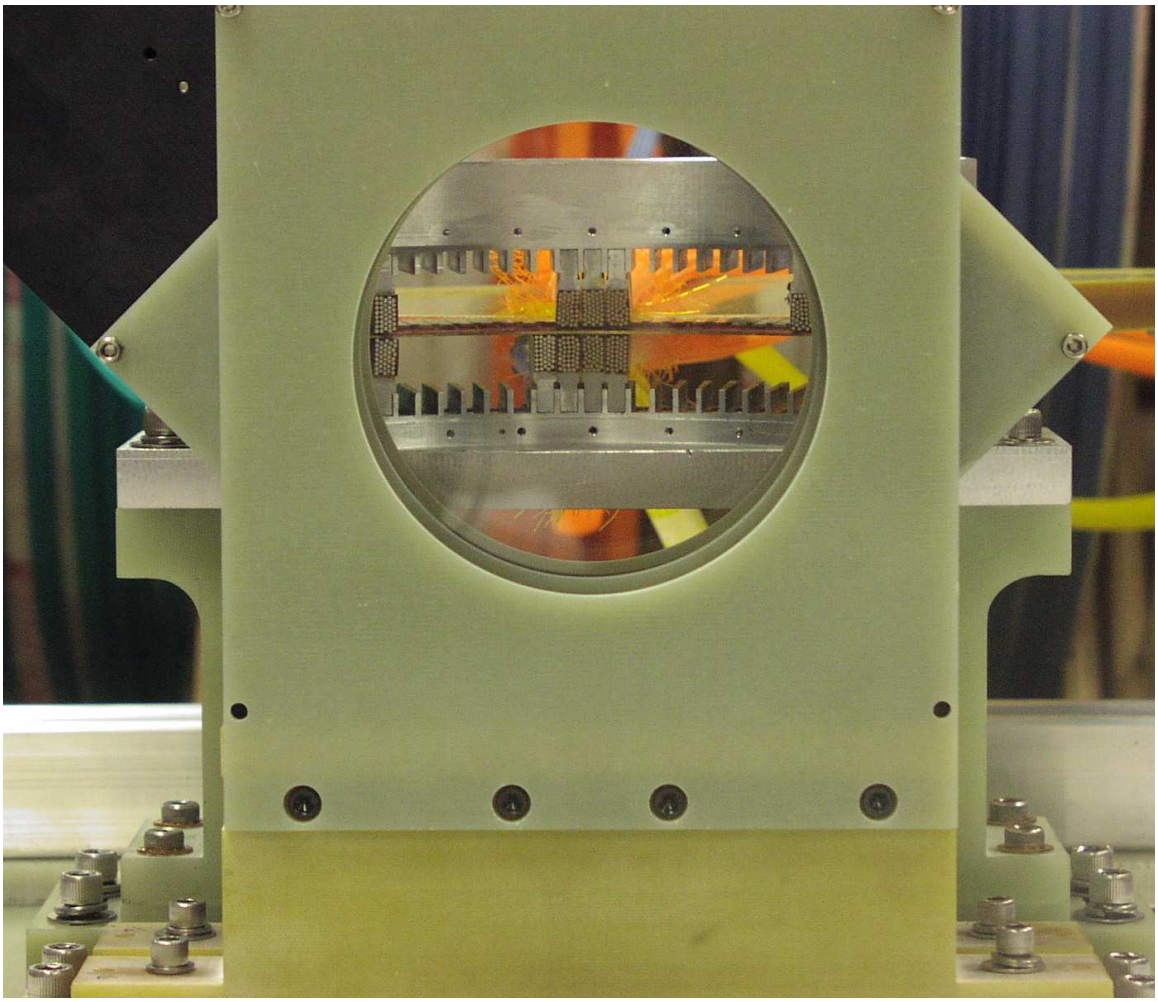
MSE-CIF Layout on NSTX

Nova Photonics, Inc.



Fiber Optic Holder

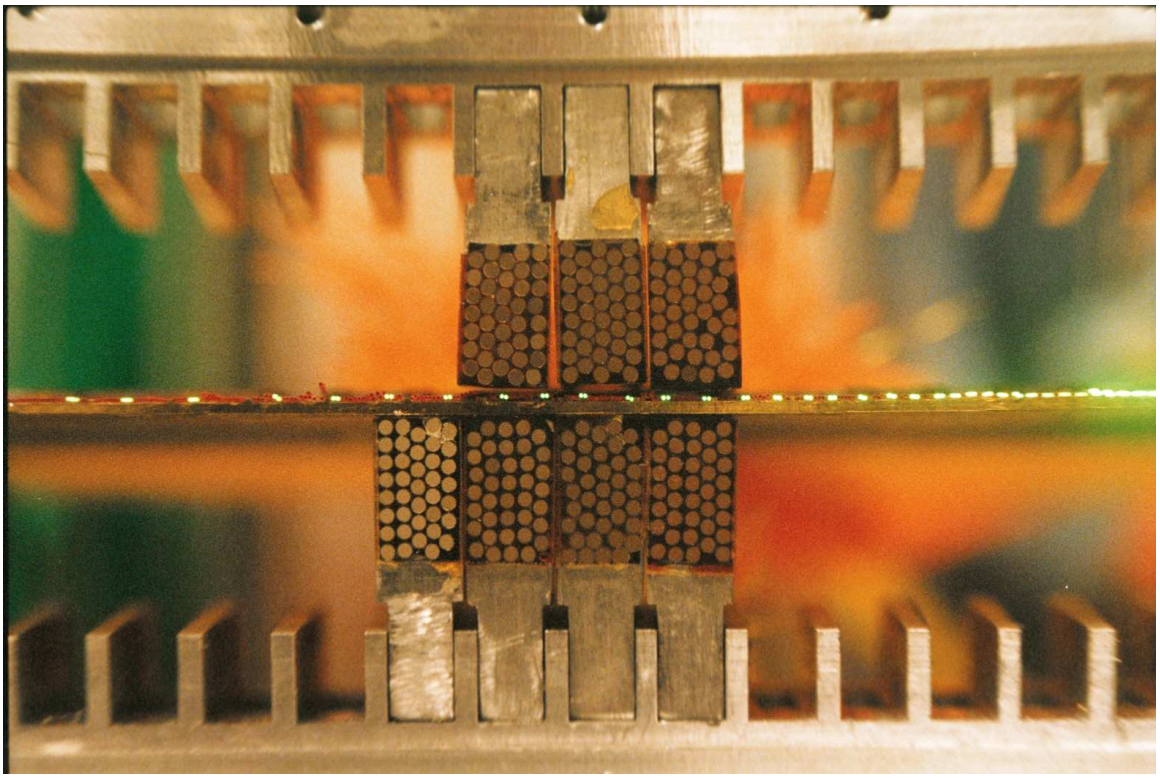
Nova Photonics, Inc.



- View of fiber holder with a few fiber ferrules installed.
- Fiber holder is now fully populated and installed on NSTX.

MSE & CHERS Fiber Optic Holder

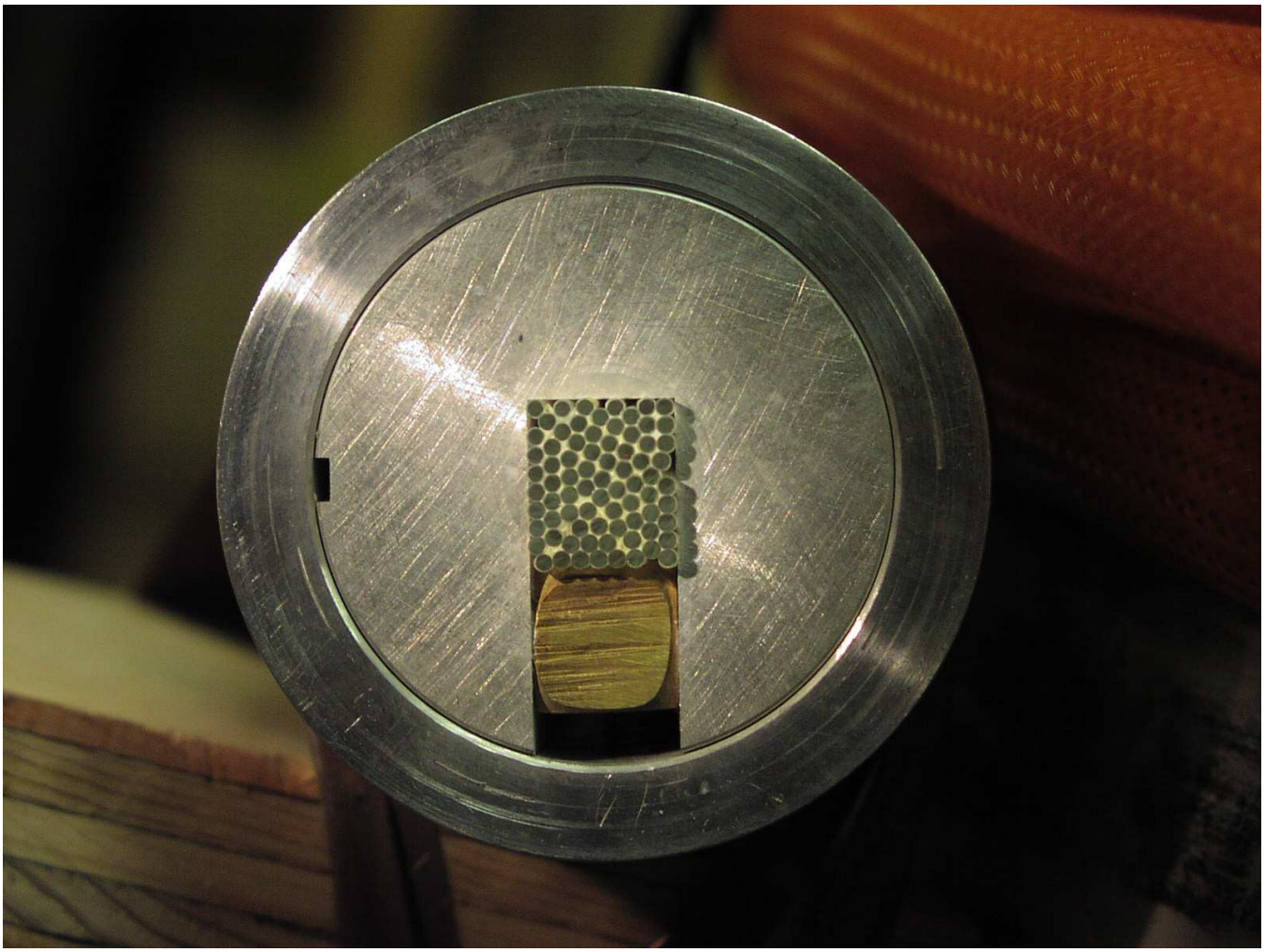
Nova Photonics, Inc.



- View of fiber holder with a few MSE fiber ferrules installed.
- CHERS fibers are the small fibers in the midplane. Ratio of light collection is about 1000:1.

Output Fiber Optic Holder

Nova Photonics, Inc.



Status and Summary

Nova Photonics, Inc.

- **Installation of collection optics and fiber optics is complete.**
- **Development of a *tunable*, *high resolution*, *high throughput* spectral filter is complete.**
- **First light in early 2004.**
- **Goal: 10 channels operating during next NSTX run and 19 channels in 2005.**